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NATIONAL COMMUNICATIONS SYSTEM

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TECHNICAL INFORMATION BULLETIN
88-7

THE EFFECTS OF HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) ON THE NORTHERN TELECOM INC. DMS-100™ SWITCH

VOLUME I

EXECUTIVE SUMMARY

SEPTEMBER 1988

OFFICE OF THE MANAGER
NATIONAL COMMUNICATIONS SYSTEM
WASHINGTON, D.C. 20305

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This report is part of a three volume set that presents the results of simulated High-Altitude Electromagnetic Pusle (HEMP) testing of a Northern Telecom Inc. DMS-100 Switching system. This volume presents a brief discussion of the test events and the test results, and summarizes the conclusions and recommendations of the test program.

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VOLUME I

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NCS TECHNICAL INFORMATION BULLETIN 88-7

THE EFFECTS OF HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) ON TELECOMMUNICATIONS ASSETS

SEPTEMBER 1988

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and Standards

FOREWORD

The National Communications System (NCS) is an organization of the Federal Government whose membership is comprised of 23 Government entities. Its mission is to assist the President, National Security Council, Office of Science and Technology Policy, and Office of Management and Budget in:

- The exercise of their wartime and non-wartime emergency functions and their planning and oversight responsibilities.

- The coordination of the planning for and provision of National Security/ Emergency Preparedness communications for the Federal Government under all circumstances including crisis or emergency.

In support of this mission the NCS has initiated and manages the Electromagnetic Pulse (EMP) Mitigation Program. The objective of this program is the removal of EMP as a significant impediment to timely reestablishment of regional and national telecommunications following an attack against the United States that includes high-altitude nuclear detonations. The program approach involves estimating the effects of High-altitude EMP (HEMP) on telecommunication connectivity and traffic handling capabilities, assessing the impact of available HEMP mitigation alternatives, and developing a comprehensive plan for implementing mitigation alternatives. This report summarizes EMP test results on the NTI DMS-100 as they apply to the EMP Mitigation Program.

Comments on this TIB are welcome and should be addressed to:

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PREFACE

This report is part of a three volume set that presents ~~the results of~~ simulated High Altitude Electromagnetic pulse (HEMP) testing of a Northern Telecom Inc. DMS-100™ switching system. The efforts described herein were funded by the Office of the Manager, National Communications System (OMNCS) and were performed by US Army Harry Diamond Laboratories (HDL) and by Booz•Allen and Hamilton Inc., Northern Telecom, Inc. (NTI), and Bell Northern Research (BNR) under HDL Contract Number DAAL02-86-D-0042, Delivery Order Numbers 7, 18, 35, and 43.

The technical contributors from HDL include J. Miletta (Program Manager), R. Reyzer (Project Leader), L. Ambrose, W. Coburn, A. Hermann, C. Reiff, and D. Troxel. The technical contributors from Booz•Allen include R. Balestri, A. Bueno, R. Henrickson, D. Palleta, W. Shiley, and T. Styer. Technical contributors from NTI/BNR include A. Childerhose, D. Dowse, J. Edwards, A. Hussein, D. O'Connor, and J. Skinner.

This volume presents a brief discussion of the test events and the test results, and summarizes the conclusions and recommendations of the test program. Volume II is a detailed description of the test procedures, the test results, and the mitigation alternatives evaluated. Volume II also presents a discussion of the conclusions and recommendations of the program. Volume III describes the post test analysis of the measured electromagnetic fields and induced transients. Volume III also includes a comparison of the characteristic attributes of the various simulator environments.

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ACRONYMS

AC	Alternating Current
AESOP	Army EMP Simulator Operation Pulser
BNR	Bell Northern Research
CCC	Central Control Complex
CMC	Central Message Controller
CO	Central Office
CPM	Central Processor And Memory
CPU	Central Processor Unit
DC	Direct Current
DDU	Disk Drive Unit
DNPC	Dual Network Packaged Core
DS	Data Store
DTM	Dual Tone Multi-frequency
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
FSP	Frame Supervisory Panel
HDL	Harry Diamond Laboratories
HEMP	High-altitude Electromagnetic Pulse
IC	Integrated Circuit
IOC	Input/Output Controller
kV	Kilovolt
LCM	Line Concentrating Module
LTC	Line Trunk Controller
MAP	Maintenance and Administration Position
MDF	Main Distribution Frame
MEB	Message Exchange Bus
MTD	Magnetic Tape Drive
MTM	Maintenance Trunk Module
NCAM	Network Connectivity Analysis Model
NM	Network Module
NSDD	National Security Decision Directive
NSEP	National Security Emergency Preparedness
NTI	Northern Telecom Incorporated
OEM	Original Equipment Manufacturer
OMNCS	Office of the Manager, National Communications System
OV	Overvoltage
PCAM	Packaged Core Auxilliary Module
PCGM	Packaged Core General Module
PCLM	Packaged Core Line Module
PCM	Pulse Code Modulation
PCMM	Packaged Core Memory Module
PCSM	Packaged Core Service Module
PCTM	Packaged Core Trunk Module
PM	Peripheral Module
PS	Program Store

PSN	Public Switched Network
PCPM	Packaged Core Power Module
REPS	Repetitive EMP Simulator
RLCM	Remote Line Concentrating Module
STM	Service Trunk Module
TEM	Transverse Electromagnetic
TM	Trunk Module
TM8	TM-type, 8 Wires
UV	Undervoltage
VDU	Video Display Unit
WRF	Woodbridge Research Facility

EXECUTIVE SUMMARY

This report presents the results of testing the Northern Telecom Inc. (NTI) DMS-100[1] family of digital telephone switch as to simulated High Altitude Electromagnetic Pulse (HEMP) fields at the U.S. Army Harry Diamond Laboratories (HDL) Woodbridge Research Facility (WRF). The test was sponsored by the Office of the Manager, National Communications System (OMNCS) to characterize the response of a typical DMS-100 switch to HEMP fields produced from a nuclear explosion. The data are to be used to support the OMNCS's statistical models for describing network performance following a HEMP event.

CONCLUSIONS

The main conclusion of the DMS-100 HEMP testing for the OMNCS is that there were no hardware failures affecting call processing. Despite temporary upsets, which affected call processing, the switch fully recovered from each shot, although manual intervention was required in some instances. There were hard failures of OEM keyboards and upsets of power supply rectifiers, which both require manual intervention, but don't immediately affect call processing. Hardware and software modifications were identified that would eliminate the need for operator intervention to ensure complete recovery of call processing capabilities.

BACKGROUND

In response to Executive Order 12472 (E.O. 12472) and National Security Decision Directive 97 (NSDD-97), the OMNCS sponsors the EMP Mitigation Program. The objective of the program is to ensure the continued availability of the National Security Emergency Preparedness (NSEP) telecommunication capabilities following a nuclear attack against the United States. The EMP Mitigation Program methodology involves identifying critical telecommunication assets, evaluating the effects of HEMP on selected telecommunication elements, evaluating the effects of HEMP on selected telecommunication networks, and assessing alternative strategies for mitigating the effects of HEMP.

To attain the goals of the OMNCS, the EMP Mitigation Program attempts to maximize the value of the limited HEMP response data available to the OMNCS. The program is not meant to be a survivability assessment program in the traditional sense. To understand the limitations, it is important to understand the constraints that the OMNCS faces. To begin with, there are a large number of assets in the Public Switch Network (PSN). Although many of these assets may be of the same type, such as the DMS–100, they can be implemented in various different configurations. In addition, the OMNCS is not empowered to force a standard configuration for each type of assets. Given these constraints, the OMNCS must attempt to prioritize the tasks and to obtain a general, network-level understanding of the HEMP response of the assets. The type of testing recommended will obtain data that are not applicable to any particular asset, but are representative of assets in the telecommunications networks of interest to the OMNCS. The data collected can then be used in a statistical method to describe these assets. In this manner, the OMNCS can maximize the value of the information that is collected.

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1 The term DMS-100 is used throughout this report to represent the switch tested, which was an NTI MSL-100.

The OMNCS EMP Mitigation Program identifies critical telecommunications assets based on postulated NSEP telecommunications requirements. The NTI DMS-100 family of digital telephone switches has been identified as such an asset. The DMS-100 is a solid-state switch that contains large line/trunk capacity. **Figure ES-1** shows the major components of the switch tested.

In accordance with the goals of this program, the DMS-100 was tested to characterize its response to the HEMP environment and to investigate alternative mitigation approaches. The OMNCS requested the assistance of Harry Diamond Laboratory (HDL) to lead the effort of assessing and testing a representative DMS-100 switch system. HDL has HEMP simulation capabilities and experience with HEMP assessments and testing of telecommunications systems.

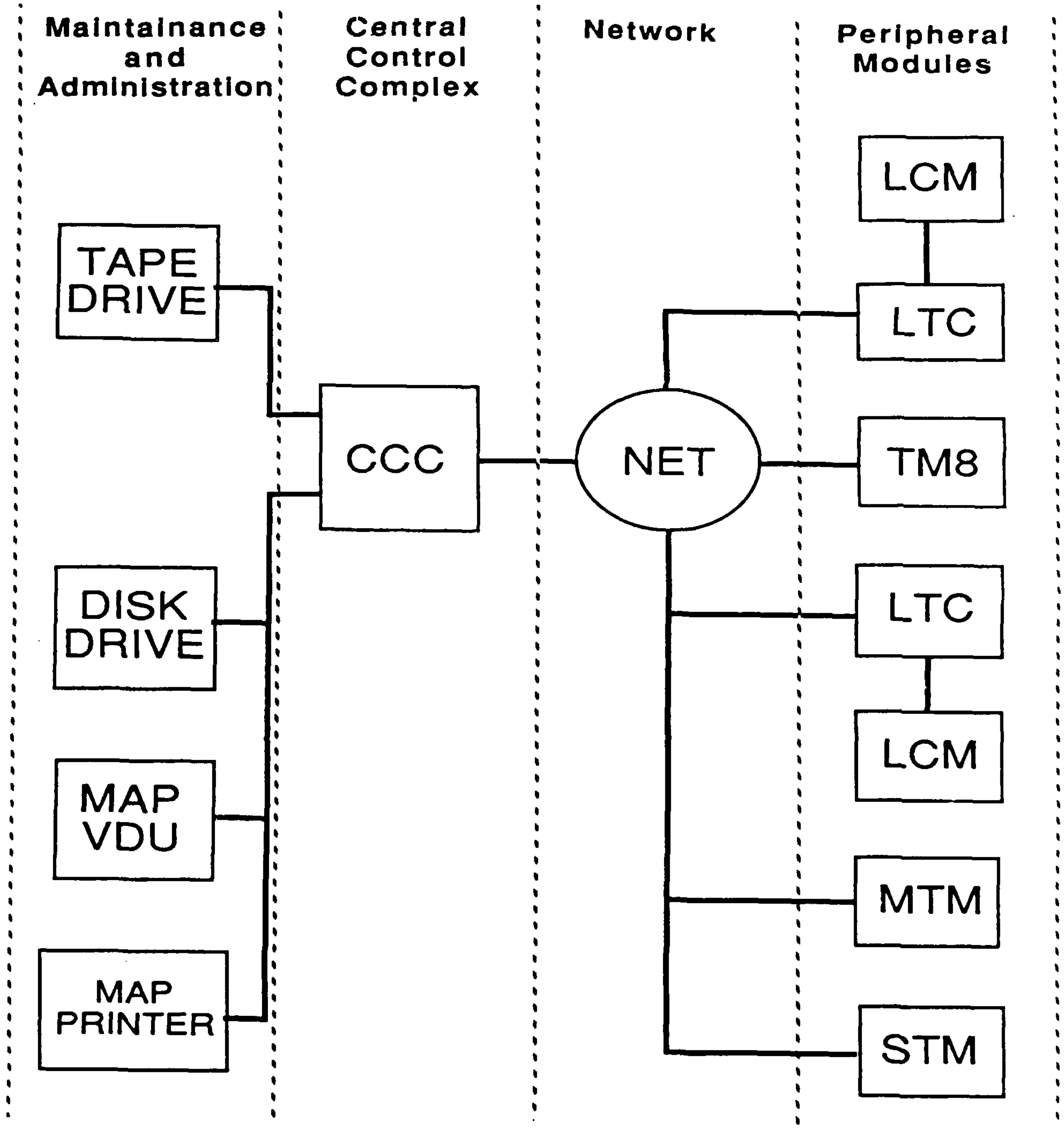
The results of the testing are used to evaluate the effects of HEMP on telecommunications networks. Using statistical methods, the test results are used to describe the HEMP response of various nodes in the network. With this knowledge, the response of the networks of interest to the OMNCS can be predicted.

TEST APPROACH

The test article consisted of representative subsystems for a typical switch installation and was configured to resemble realistic interconnections between major components of a variety of switch system applications. The modules and the simulated traffic distribution implemented in the DMS-100 test are shown in **Figure ES-2**. The test article could only approximate the configuration of any fielded DMS-100 because of the numerous possible configurations of the switch. However, all important subsystems were included in the test. For the needs of the OMNCS, the testing of this representative DMS-100 is sufficient to provide the general HEMP response of the switches that are used in the network assessment. In addition, the switch was tested with various combinations of Electromagnetic Interference (EMI) shielding and circuit improvements. Data were collected to support the OMNCS network assessment methodology. The data required for the assessment are the operational performance of the DMS-100 in terms of hardware damages and upsets. The status of various computer controlled functions were monitored with two primary diagnostic tools. The first is the maintenance administration position, or MAP, which provides a variety of alarms, status reports, and diagnostic test reports on both a cathode ray tube (CRT) monitor and a printer. The second is a diagnostic/test tool known as a "load box", which simulates calls to and from the switch and provides printed reports of call processing performance as testing progresses.

For the needs of the OMNCS network assessment, only the test data related to the configurations that are in presently fielded switches or will be in the future fielded switches are used in the statistical model. NTI offers an EMI protected version of the DMS-100, at an additional cost and intends to incorporate EMI shielding techniques into the design of future generations of switches; however, switches currently fielded in the PSN and those currently being purchased by the telecommunications industry are mainly of the non-EMI protected version. Therefore, the primary test results addressed in this Executive Summary represent the switch without EMI shielding or filtering.

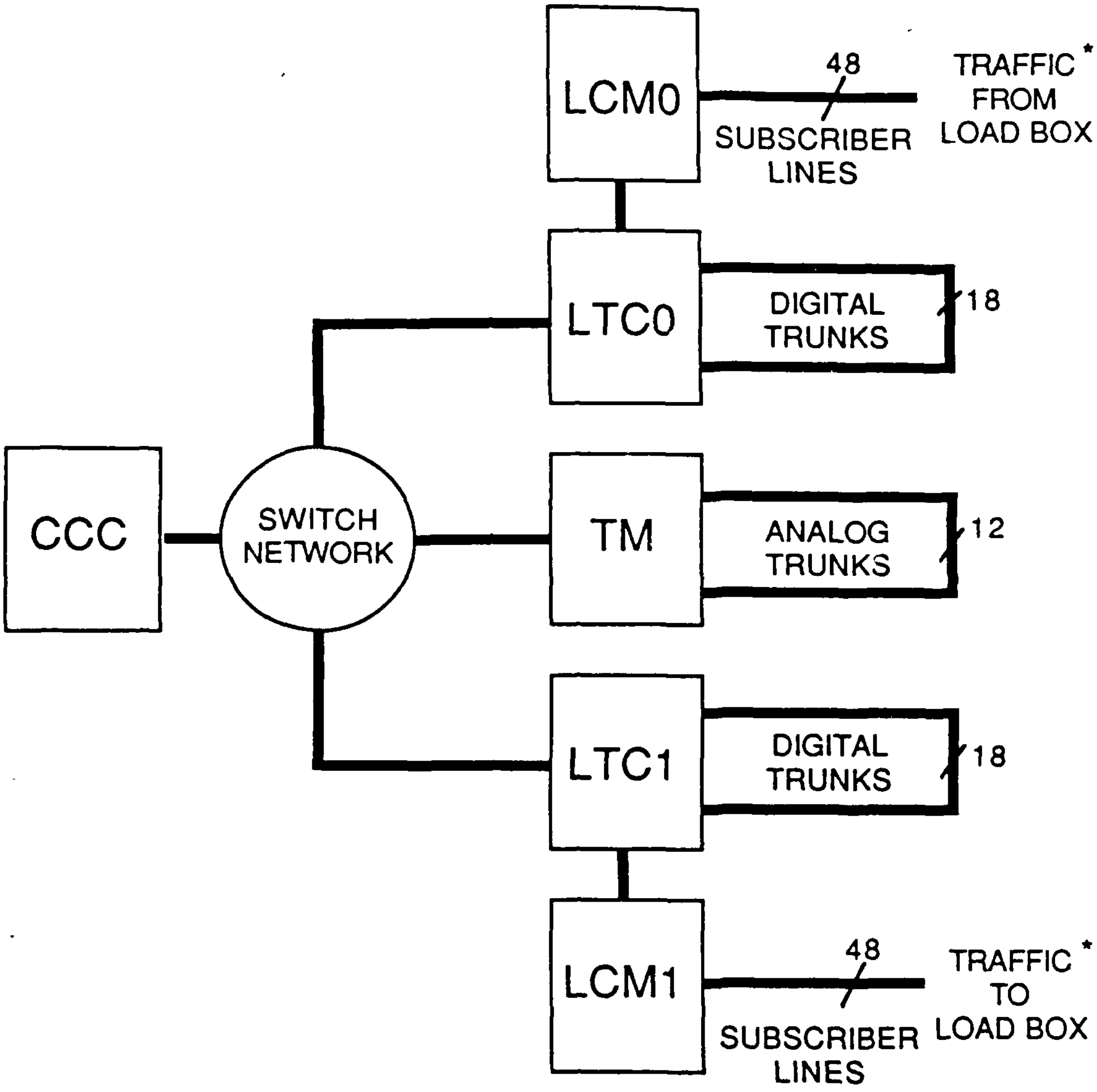
Exposure of the switch to simulated HEMP took place in three major phases. The first phase was low field strength (2.5 kV/m), free field pulsed illumination test of the test article in Ottawa. Ottawa was chosen for the proximity of the Bell-Northern Research



NOMENCLATURE

LCM - Line Concentrating Module
LTC - Line Trunk Controller
TM8 - Trunk Module (8 Wires)
MTM - Maintenance Trunk Module
NET - Network
STM - Service Trunk Module
MAP - Maintenance And Administration Position
CCC - Central Control Complex

Figure ES-1. Major DMS-100 Component Interconnections



LEGEND:

CCC - Central Control Complex

LCM - Line Concentrating Module (Subscriber Line Interface)

LTC - Line Trunk Controller (Digital Trunk Interface)

TM - Trunk Module (Analog Trunk Interface)

* Only 36 out of the 48 links were operational in Ottawa.

Figure ES-2. Traffic Link Distribution for the HEMP Test

facility, where technical support personnel are located. The second phase involved shipment of the equipment to Woodbridge, VA, for illumination test under the Harry Diamond Laboratories REPS simulator, at somewhat higher field strengths (10 kV/m). The third phase consisted of exposing the test equipment to the threat-level field strengths, which were at the HDL AESOP simulator (33-70 kV/m). During each phase, system call processing performance was monitored and induced transients were measured. **Table ES-1** indicates the number of test events for each of the different tests configurations.

SUMMARY OF TEST RESULTS

The following is a concise summary of the test results. Only the details that are applicable to the needs of the OMNCS are summarized. The intricate details may be found in Volume II.

Tables ES-2, ES-3, and **ES-4** summarize the test results and the interpreted data that should be used by the OMNCS for its survivability models. The model data differ from the raw data because, for the statistical model, the assumption is made that survivals in the higher bin indicate survivals in the lower bins. Therefore, for example, the sample size and survivals in the first bin are a sum of all three bins.

Without the hardware and software modifications that NTI plans to include as part of all future switches, the DMS-100 switch is survivable to HEMP effects, but vulnerable to upset. **Table ES-2** includes the data to be used for the Network Connectivity Analysis Model (NCAM) statistical assessments where switch locations are assumed to be staffed and manual intervention is available. This table presents all data recorded during testing of the unshielded switch and includes data from both single and multiple pulses.

With the hardware and software modifications in place, the DMS-100 switch automatically recovered to 100 percent call processing capability within 20 minutes. **Table ES-3** includes all data to be used for NCAM statistical assessments where switch locations are not assumed to be staffed and manual intervention is not available. This table includes all data for the switch in the final (modified) configuration. In this configuration, the switch was tested with only multiple pulses under AESOP at 60 kV/m. As a result of the modifications, call processing was unaffected or returned to 100 percent without manual intervention.

With the EMI protection package in place, the DMS-100 was much less susceptible to HEMP, with only one interruption of call processing for 82 test events. **Table ES-4** includes the data to be used for NCAM statistical assessments for which interrupted call processing is of interest. The use of these data presumes that all switches have the EMI protection package installed, which also eliminates the need for manual intervention. With no EMI package installed, the switch suffered some degree of call processing interruption for virtually every pulse under REPS and AESOP.

The time required for the switch (without EMI protection) to recover after a simulated HEMP event is summarized in **Figures ES-3, ES-4**, and **ES-5**. **Figure ES-3** shows the average times of call processing recovery for the various field strengths produced by the simulators. Also indicated are the standard deviations of the recovery times. **Figures ES-4** and **ES-5** present the distributions of recovery times for medium (10-30 kV/m) and high (50-70 kV/m) HEMP stress ranges, respectively.

CONFIGURATIONS	Ottawa 2.5 kV/m	REPS 10 kV/m	AESOP 33 kV/m	AESOP 48 kV/m	AESOP 60 kV/m	AESOP 69 kV/m	Total
Panels On Filters On	824	36	14	15	14	3	906
Panels On Filters Off	—	—	5	—	7	—	12
Panels Off Filters On	83	24	17	—	—	—	124
Panels Off Filters Off	109	59	30	48	54	—	300
LCM Frames Unshielded	—	—	—	—	4	—	4
LCM Frames Unshielded LCM Cable Looped Around	—	—	—	—	26	—	26
Total	1016	119	66	63	105	3	1372

Table ES-1. Summary of Number of Test Events (Pulses) for Each Configuration

Stress Level (kV/m)	Raw Data		Model Data	
	Sample size	Failures	Sample size	Failures
10-30	59	0	191	0
30-50	78	0	132	0
50-70	54	0	54	0

*Data Included: All data for unshielded configurations.

Table ES-2. DMS-100 Test Results: Manual Intervention Available

Stress Level (kV/m)	Raw Data		Model Data	
	Sample size	Failures	Sample size	Failures
10-30	0	0	33	0
30-50	0	0	33	0
50-70	33	0	33	0

*Data Included: All data for unshielded configurations with all hardware and software modifications.

Table ES-3. DMS-100 Test Results: Manual Intervention Not Required

Stress Level (kV/m)	Raw Data		Model Data	
	Sample size	Upsets	Sample size	Upsets
10-30	36	0	65	0
30-50	29	0	29	0
50-70	17	1	17	1

*Data Included: All data for the shielded configurations

Table ES-4. EMI Protected DMS-100 Test Results: Manual Intervention Not Required

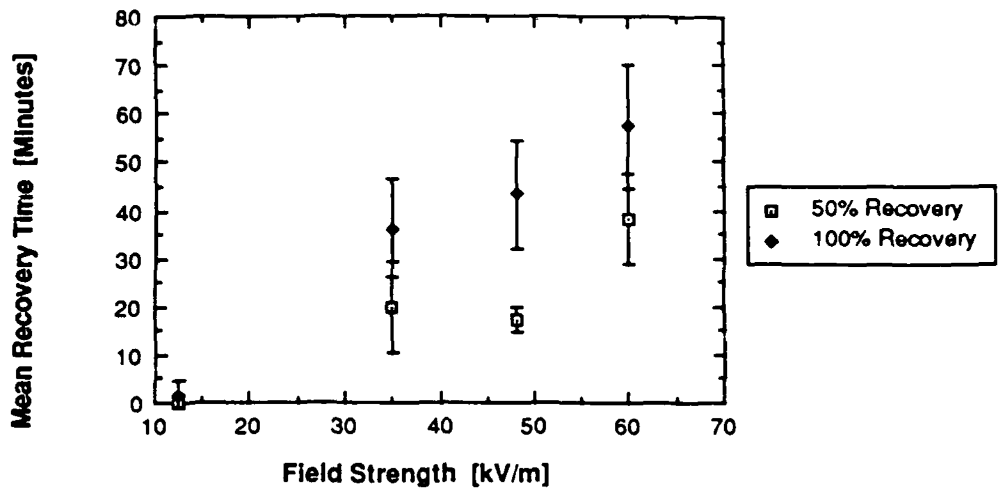


Figure ES-3. Summary of Mean Recovery Times Under HDL Simulators

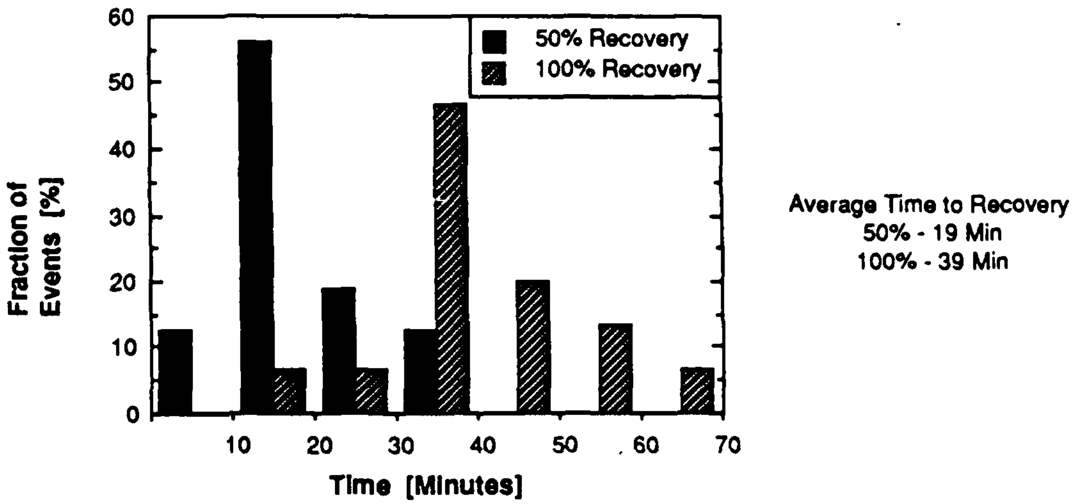


Figure ES-4. Recovery Time Distribution for Medium HEMP Stresses (30-50kV/m)

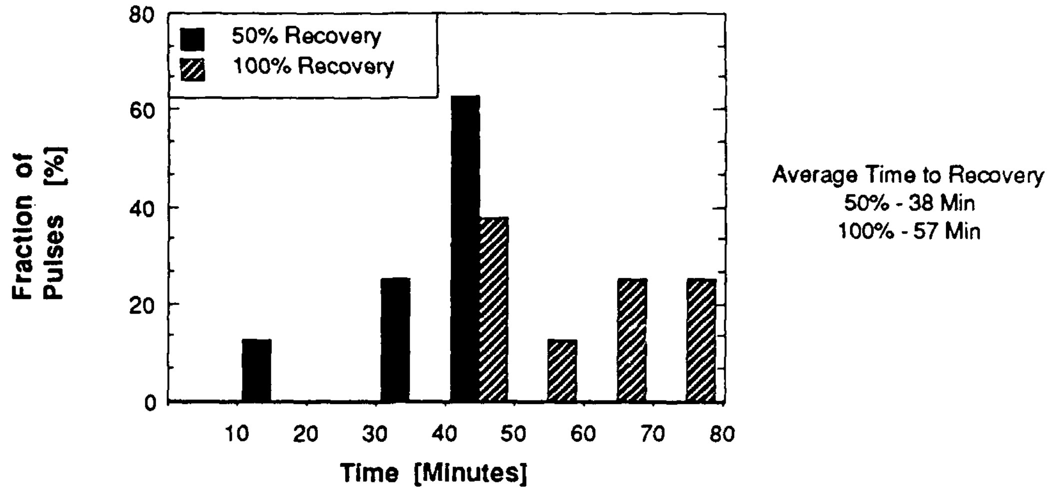


Figure ES-5. Recovery Time Distribution for High HEMP Stresses (50-70 kV/m)

OBSERVATIONS

In addition to the relevant data gathered for the OMNCS model, the testing provides several other observations about the testing methods and the actual DMS-100 configuration. This data can be used in drawing other conclusions and recommendations for the DMS-100 switch.

During the testing of the switch, different grounding configurations were used. Although these configurations had a distinct effect on the coupled waveforms, there was no effect on the call-processing capabilities. This may indicate that test results are valid for a wide variety of grounding configurations.

The different configurations in which the switch was tested also provide some insight into its HEMP susceptibility. The EMI shielding for the switch is provided by line filters and special panels. The use of panels without the filters seems to provide HEMP protection for the CCC and the backplane wiring. Conversely, the use of filters without the panels seems to provide protection for the LCMs.

Hardware and softwa-e improvements to provide automatic recovery from upsets in the switch were also identified during the testing. The hardware fixes included replacing the supervisory chips in the power converter units with less sensitive chips and placing a .01 F ceramic capacitor on the rectifier control board. The software fix is to include an "autoload" package to reload and restart the system. Implementation of these fixes eliminates the need for manual intervention.

The only hardware failure observed during the test was in the OEM keyboard. The failure was traced to a damaged transmit/receive circuit in the keyboard. However, this has no direct impact on the switch's call processing because the operation of the switch can be independent of the keyboard.

RECOMMENDATIONS

The test data have shown that there are various methods for eliminating the need for manual intervention or preventing upsets from occurring. It is recommended that the supervisory chips be replaced, the capacitor be placed on the rectifier board, and the autoload software be implemented. Although these changes will not prevent the switch from upsetting, the switch will automatically recover from any upsets. To prevent upsets, it is recommended that the EMI protection package be installed in any switch whose uninterrupted operation is deemed critical to NSEP requirements.

Although the different grounding configurations did not affect call-processing, there was a significant increase in the coupled waveform. It is recommended that the different possible grounding configuration be evaluated to determine the potential impact of alternative grounding schemes on the ability of the PSN to support NESP initiatives. Power converters have been discovered to be a problem in both the testing of the DMS-100 and the 5ESS.™ This may indicate that such problems may be pervasive in the PSN. It is recommended that the HEMP susceptibility of the power converters in the assets of the PSN be investigated.

A last recommendation is to investigate the HEMP susceptibility of terminals and keyboards connected to PSN switches. The present HEMP testing has shown that the keyboard can be damaged. In this case, the call-processing function is not affected. However, it may be important to determine the severity of the problem for terminals and keyboards in general, and to determine the potential impact on the performance of the PSN.

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